# ANALYSIS OF FILM CONDENSATION IN HORIZONTAL MICROCHANNELS WITH VARIOUS CHANNEL SHAPES USING ANSYS

**Arranged as a requirement to complete Undergraduate Study Program in Mechanical Engineering, Engineering Faculty**

By:

**MU'AMMAL ASHSHIDDIQI**
**D200133011**

**MECHANICAL ENGINEERING DEPARTMENT**

**ENGINEERING FACULTY**

**UNIVERSITAS MUHAMMADIYAH SURAKARTA**

**2017**

## VALIDATION SHEET

This final project report had been finished in the Universiti Tun Hussein Onn Malaysia and met the requirement for the award of the Bachelor Degree of Mechanical Engineering with Honor in Universitas Muhammadiyah Surakarta.

Composed by : Mu'ammal Ashshiddiqi D200133011
Department : Mechanical engineering (international program)

| Author | Known by,<br>Secretary of international program |
|---|---|
| Mu'ammal Ashshidddiqi | Wijianto, ST. M.Eng.Sc |

**UNIVERSITI TUN HUSSEIN ONN MALAYSIA**

**STATUS CONFIRMATION FOR UNDERGRADUATE PROJECT REPORT**

**ANALYSIS OF FILM CONDENSATION IN HORIZONTAL MICROCHANNELS WITH VARIOUS CHANNEL SHAPES USING ANSYS**

**ACADEMIC SESSION : 2016/2017**

I, **Mu'ammal Ashshiddiqi,** agree to allow this Undergraduate Project Report to be kept at the Library under the following terms:

1. This Undergraduate Project Report is the property of the Universiti Tun Hussein Onn Malaysia.
2. The library has the right to make copies for educational purposes only.
3. The library is allowed to make copies of this report for educational exchange between higher educational institutions.
4. ** Please Mark (√)

| | | |
|---|---|---|
| ☐ | CONFIDENTIAL | (Contains information of high security or of great importance to Malaysia as STIPULATED under the OFFICIAL SECRET ACT 1972) |
| ☐ | RESTRICTED | (Contains restricted information as determined by the organization/institution where research was conducted) |
| ☑ √ | FREE ACCESS | |

Approved by,

(WRITER'S SIGNATURE)

(SUPERVISOR'S SIGNATURE)

DR. AKMAL NIZAM BIN MOHAMMED

DR. AKMAL NIZAM BIN MOHAMMED
Senior Lecturer
Department of Plant and Automotive Engineering
Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

Permanent address :
RT 03/RW 04 Brengkok, Brondong, Lamongan 62263, Jawa Timur, Indonesia.

Date : 15/06/2017

Date : 15/06/2017

NOTE:

** If this Undergraduate Project Report is classified as CONFIDENTIAL or RESTRICTED, please attach the letter from the relevant authority/organization stating reasons and duration for such classifications.

# DECLARATION

I hereby declare that the work in this present project is my own except for quotation and summaries which have been their sources and acknowledged.

Student : ..............................................................

MU'AMMAL ASHSHIDDIQI

Date : ..............................................................

Supervisor : ..............................................................

DR. AKMAL NIZAM BIN MOHAMMED

Date : 15 / 06 / 2017

ANALYSIS OF FILM CONDENSATION IN HORIZONTAL MICROCHANNELS WITH VARIOUS CHANNEL SHAPES USING ANSYS

Mu'ammal Ashshiddiqi[1]

[1] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia

Abstract

The film condensation of refrigerant R-134a in circular (diameter 1 mm), triangular (side 1 mm), inverted triangular (side 1 mm), square (side 0.5, 1, 2, 3, 5 mm), rectangular (sides 1x1.5 and 1.5x1 mm) are numerically studied through ANSYS Fluent 16.1. The effect of channel shape is investigated where the wall temperature is uniform with velocity inlet of vapor 3 $ms^{-1}$ and vapor inlet temperature at 90$^oC$. The results showed that The film thickness is grow gradually in 0-100 mm from inlet and then has not much change along 200 mm – outlet. Although the film thickness is generated in every microchannel and even the film generated is almost equally (except square with side 5 mm), the square channel come out with higher heat transfer coefficient than other channel shapes**.**

Filem kondensasi oleh *refrigerant* R-134a dalam penampang lingkaran (diameter 1 mm), segi tiga (sisi 1 mm), segi tiga terbalik (sisi 1 mm), persegi (sisi 0.5, 1, 2, 3, 5 mm), persegi panjang (sisi 1x1.5 dan 1.5x1 mm) dibahas secara numeris melalui ANSYS Fluent 16.1. Efek dari bentuk kanal ini diteliti dengan kondisi suhu dinding yang seragam dengan kecepatan uap pada daerah inlet 3 $ms^{-1}$ dan suhu uap inlet 90$^oC$. Hasil yang didapat menunjukkan bahwa ketebalan filem bertambah secara bertahap di daerah 0-100 mm dari inlet dan tidak banyak menunjukkan perubahan sepanjang 200 mm – outlet. Meskipun ketebalan filem dihasilkan pada setiap mikrokanal dan semuanya mempunyai ketebalan filem yang hamper sama (kecuali persegi dengan sisi 5 mm), kanal dengan bentuk persegi mempunyai koefisien transfer kalor yag paling tinggi dibandingkan dengan kanal dengan bentuk yang lain.

***Keywords : Microchannel; Film Condensation; Simulation; R-134a; Channel shapes***

## 1. Introduction

Microchannels are used in fluid control and to improve heat transfer performance with typical dimension below 1 mm. Wang and Rose [1] once emphasized that some different methods are needed to treat larger channels when the channels dimension is around 1 mm or less because it generate surfaces tension effect.

In microchannels condensation, channel shape would affects flow, and every geometries has different treatment. This theory was proved by some researches about microchannels condensation based on its channel shape. Based on author knowledge, there are still a few research about microchannels condensation based on its channel shape, some of these compared two or three channel shapes and the rest only review microchannels condensation in a single shape. Thus this study would try to compare microchannels condensation in some channel shapes. The present study is aimed to simulate and analyze film condensation in horizontal microchannels with various channel shapes through ANSYS Fluent.

The present work relates to condensation in horizontal microchannels and concentrated in its channel shape. The condensation were observed in square, rectangular, triangular and circular microchannels. Same topic was investigated by Wang and Rose [1] using theoretical approach with R134a as refrigerant. They emphasized that the non-circular channels performs better than the circular channel near the inlet and the heat transfer coefficient was the highest at square channels followed by rectangular, triangular and circular at near inlet region.

## 2. Literature review

There are some researchers that carried out about condensation in some certain channel shape. Some of them tried to compare the effect of channel shape while the rest investigated microchannels condensation in a certain channel shape. In the present study, the author will show some related studies briefly. Those are :

Hao et al. [2] analized about flow regime transition from laminar flow to intermitten flow of steam condensation in noncircular microchannels. They emphasized that the transition flow occurs further downstream, and the annular flow regime is expanded in the trapezoidal and triangular microchannels compared with rectangular microchannel with the same hydraulic diameter.

Heo et al. [3] investigated condensation heat transfer and pressure drop of $CO_2$ in three different diameter of rectangular microchannels and the number of ports were 7,19 and 23. They conducted the experiment in rectangular microchannel that had hydraulic diameter 1.5, 0.78, and 0.68 mm for the 7, 23and 19 ports, respectively. The test temperature ranged from -5 to 5 $^oC$ and the range of the mass flux was from 400 to 800 kg/m$^2$s. The result revealed that the highest pressure drop was found in the microchannel of 23 ports.

Chen et al. [4] simulated about condensation flow in a rectangular microchannel. They used refrigerant FC-72 and the condensation flow investigated in a rectangular microchannel with a 1-mm hydraulic diameter using the volume of fluid (VOF) model numerically. The simulation showed that the vapor phase in the microchannel forms a continuous column with a decreasing diameter from upstream to downstream. The liquid temperature is close to saturation near tha interface, lower downstream and in thin liquid layer close to the cooling surface. The result also revealed that the initial bubble size increases with the increasing flow mass flux or decreasing cooling heat flux.

Mghari et al. [5] investigated about condensation heat transfer enhancement in a horizontal non-circular microchannel. They conducted steam condensation in a non-circular microchannel through numerical investigation. They showed that the enhancement factor of the heat transfer coefficient reaches 100% by increasing the contact angle from 6$^o$ to 15$^o$ and their investigation result revealed that the lowest average Nusselt numbers are obtained from the square microchannel.

Jiang et al. [6] have carried out visualization and measurement experiment on flow condensation of ethanol-water mixtures in the trapezoidal microchannels. The annular, droplet injection and bubble flow patterns were observed in the microchannels under different inlet ethanol mass concentration. In this experiment, the relation between flow patterns and surface energy difference between mixture vapor condensate and ultra-thin liquid film in the microchannel were investigated.

Fronk and Garimella [7] investigated about condensation of carbon dioxide in rectangular microchannels. The test section is cooled by chilled water circulating at a high flow rate to ensure that the thermal resistance on the condensation side dominates. The experiment data showed a trend of increasing heat transfer coefficient and pressure drop at lower reduced pressure and increasing quality.

Kaew-on et al. [8] conducted an experimental investigation on the condensation heat transfer characteristic of R-134a flowing inside mini circular and flattened tubes. The experiment was investigated in a circular tube and 3 flattened tubes. The result revealed that the condensation heat transfer coefficient increased with increasing mass flux, heat flux, and vapor quality. The heat transfer coefficient of the flattened tubes were higher than that of the circular tube.

Kim et al. [9] have carried out an experimental work about filmwise and dropwise condensation inside transparent circular tubes. They conducted air-cooled condensation experiments inside bare and tetrafluoroethylene (TFE)-coated Pyrex glass tube. The result emphasized that the local condensation heat transfer coefficients in dropwise mode were much larger than those in filmwise mode. The dropwise condensation heat transfer capability was degraded while the vapor quality inside TFE-coated tube decreased.

**Nomenclature**

| | |
|---|---|
| $^{o}$C | - Degree Celcius |
| mm | - Milimeter |
| m | - Meter |
| K | - Kelvin |
| V | - Velocity |
| $\mu$ | - Dynamic Viscosity |
| $k-\omega$ | - k-omega (Turbulent flow model) |
| $\rho$ | - Density |
| $\sigma$ | - Surface tension |
| Ca | - Capillary number |
| Re | - Reynold number |
| W | - Watt |
| S | - Second |
| Dh | - Hydraulic diameter |
| P | - Pressure |

| | |
|---|---|
| h | - Heat transfer coefficient |
| $\delta$ | - Film thickness |

## 2.1 Microchannel condensation

Agarwal and Garimella [10] once developed a technique for accurately measuring the heat transfer coefficient and pressure drop during condensation of R-134a at small quality increments in rectangular microchannel test section ($0.10<D_h<0.16$ mm, AR = 1-4). They found that the condensation heat transfer and pressure drop correlations developed for macro and mini channels under predicted the data consistently.

Heo et al. [3] stated that the heat transfer coefficient increased with the decrease of condensation temperature for all mass flux condition. As the condensation temperature decreased, the liquid film on the tube wall became thinner due the variation of density ratio between the liquid and vapor, and its thermal resistance decreased. The condensation heat transfer coefficient was enhanced with decrease in the liquid film thickness, which acts as a thermal resistance in the annular flow condition.

Fronk and Garimella [7] emphasized that an accurate measurement of condensation heat transfer and pressure drop in microchannels at temperatures relevant for heat rejection applications is needed to asses tha applicability of these and other models at small $D_h$. Obtaining accurate, repeatable results is made difficult by the small condensation heat duties, low mass flow rates, and high heat transfer coefficients characteristic of microchannels and the inability to easily apply and measure a constant heat flux.

### 2.1.1 Film Condensation in Horizontal Tubes

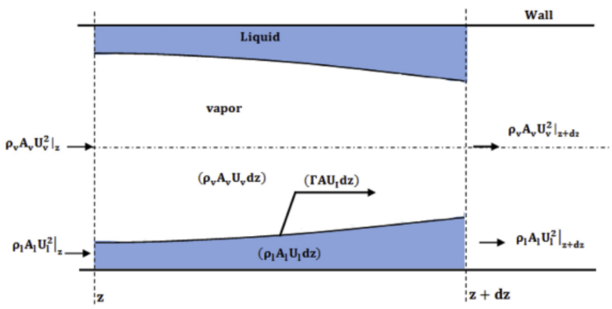



**Figure 2. 1 Film condensation inside microchannel (source : Mghari et al. 2014)**

Incropera et al. [11] reviewed that condensers used for refrigeration and air-conditioning systems generally involve vapor condensation inside horizontal or vertical tubes. Conditions within the tube are complicated and depend strongly on the velocity vapor flowing through the tube. If this velocity is small, condensation occurs in the manner depicted by figure 2.1 for horizontal tube. That is, the condensate flow is from the upper portion of tube to the bottom, from whence it flow in a longitudinal direction with the vapor.

At higher vapor velocities the two-phase flow regime becomes annular. The vapor occupies the core of the annulus, diminishing in diameter as thickness of the outer condensate layer increases in the flow direction.

## 3. Modeling

Working fluid in the present study is R-134a. R-134a is also known as Tetrafluoroethane ($CF_3CH_2F$) from the family of HFC refrigerant. With the discovery of the damaging effect of $CFC_s$ and $HCFC_s$ refrigerants to the ozone layer, the HFC family of refrigerant has been widely use as their replacement.
The another information needed for analysis are as follows :

$T_{inlet}$ : 90°C
$T_{plate}$ : 44°C
Velocity inlet : 3 $ms^{-1}$.

### 3.1 Governing equation

Most of all the equations used in the present study are provided by ANSYS. The equations below based on the ANSYS Fluent theory guide, they are as follows :

a. Basic fluid flow

Mass conservation equation

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\vec{V}) = S_m \quad (3.1)$$

Multiphase flow

$$\frac{\partial \propto_l \rho_l \emptyset_l^k}{\partial t} + \nabla.\left(\propto_l \rho_l \vec{u}_l \emptyset_l^k - \alpha_l I_l^k \nabla \emptyset_l^k\right) = S_l^k \;\; k = 1, \dots, N \quad (3.2)$$

b. Multiphase flow evaporation-condensation model

Condensation

$$\dot{m}_{vl} = coeff * \propto_v \rho_v \frac{(T_{sat} - T_v)}{T_{sat}} \quad (3.3)$$

The Clapeyron-Clausius equation, pressure to temperature for the saturation condition

$$\frac{dP}{dT} = \frac{L}{T(V_v - V_l)} \quad (3.4)$$

c. Eulerian wall films

Conservation of mass for a two dimensional film in three dimensional domain

$$\frac{\partial h}{\partial t} + \nabla_s.\left[h\vec{V}_l\right] = \frac{\dot{m}_s}{\rho_l} \quad (3.5)$$

Conservation of film momentum

$$\frac{\partial h\vec{V}_l}{\partial t} + \nabla_s.\left(h\vec{V}_l\vec{V}_l\right) = -\frac{h\nabla_s P_L}{\rho_l} + (\vec{g}_\tau)h + \frac{3}{2\rho_l}\vec{\tau}_{fs} - \frac{3v_l}{h}\vec{V}_l + \frac{\dot{q}}{\rho_l} \quad (3.6)$$

Where

$$P_L = P_{gas} + P_h + P_\sigma \quad (3.7)$$

$$P_h = -\rho h(\vec{n}.\vec{g}) \quad (3.8)$$

$$P_\sigma = -\sigma\nabla_s.(\nabla_s h) \quad (3.9)$$

Conservation of film energy

$$\frac{\partial(hT_f)}{\partial t} + \nabla_s.\left(\vec{V}_f hT_f\right) = \frac{1}{\rho C_p}\left\{2k_f\left[\frac{T_s+T_w}{h} - \frac{2T_f}{h}\right] + \dot{q}_{imp} + \dot{m}_{vap}L(T_s)\right\} \quad (3.10)$$

d. Turbulence

Shear-stress transport (SST) K-$\omega$ model

$$\mu_t = \frac{\rho k}{\omega}\frac{1}{max\left[\frac{1}{\alpha^*},\frac{SF_2}{a_1\omega}\right]} \quad (3.11)$$

Where S is the strain rate magnitude and $F_2$ is given by

$$F_2 = \tanh(\emptyset_2^2) \quad (3.12)$$

$$\emptyset_2 = max\left[2\frac{\sqrt{k}}{0.09\omega y},\frac{500\mu}{\rho y^2\omega}\right] \quad (3.13)$$

Where $y$ is the distance to the next surface.

Here are some equation used in the present study beside the equation used in ANSYS:

a. Hydraulic diameter

Circular hydraulic diameter

$$D_h = D \quad (3.14)$$

Triangular hydraulic diameter

$$D_h = \frac{4x\ area}{perimeter} \quad (3.15)$$

Square hydraulic diameter

$$D_h = \frac{4a^2}{4a} = a \quad (3.16)$$

Rectangular hydraulic diameter

$$D_h = \frac{4ab}{2(a+b)} = \frac{2ab}{a+b} \quad (3.17)$$

b. Reynold number

$$Re = \frac{\rho V D_h}{\mu} \quad (3.18)$$

c. Capillary number

$$Ca = \frac{\mu U}{\sigma} \quad (3.19)$$

d. Film thickness

$$\delta = \frac{0.67Ca^{2/3}}{1+3.35Ca^{2/3}}D_h \quad (3.20)$$

e. Heat transfer coefficient

$$h_{internal} = 0.555\left[\frac{g\rho_l(\rho_l-\rho_v)k_l^3}{\mu_l(T_{sat}-T_s)}\left(h_{fg} + \frac{3}{8}C_{pl}(T_{sat}-T_s)\right)\right]^{1/4} \quad (3.21)$$

3.2 CFD setup

Meshing used in the present study is around 500000 elements for every channel shape. From Reynold's number formula, the value of Relnold's number for each channel shape are as follow :

$Re_{circular}$ = 8266.621

$Re_{triangular}$ = 3976.244

$Re_{inv.triangular}$ = 3976.244

$Re_{square\ 0.5}$ = 4133.31

$Re_{square\ 1}$ = 8266.621

$Re_{square\ 2}$ = 16533.242

$Re_{square\ 3} \quad = 24799.861$
$Re_{square\ 5} \quad = 41333.106$
$Re_{rectangular\ 1x1.5} = \ 9919.945$
$Re_{rectangular\ 15x1} \ = 9919.945$

Because all the value of Reynold's numbers are above 2000 then the setting used in the present study was for turbulent flow. Therefore SST k-omega is used in ANSYS Fuent setup. The another setting used are energy equation, eulerian wall film and multiphase (mixture). The boundary conditions used in the present study are same as stated above. After that, the author used 2000 iteration with number of time step and time step size 1 and 0.1 s respectively.

## 4. Result and discussion

Results are presented below for condensation of R-134a in circular (diameter 1 mm), triangular (side 1 mm), square (side 0.5, 1, 2, 3, 5 mm) and rectangular (sides I mm x 1.5 mm, both orientation) channels. In all cases the inlet vapor temperature was 90 °C, the surface temperature was 44 °C taken here to be contants along the channel and inlet velocity was 3 m $s^{-1}$.

From the contours of velocity, those are showed no big different in the contour profile 300 mm to 500 mm from inlet (along z axis) or it could be said that the flow was fully develop (see APPENDIX). As for the contours of temperature showed that the temperature decrease along the channel and has a little rise in the outlet area, while the contours of pressure showed that the pressure keep decreasing along the channel.

The film thickness value was obtained from manual calculation by using the film thickness formula stated above. From the figure 4.1, it was showed that the film thickness in the every channel is too small. Figure 4.1 shown that the film growth in every channel significantly only until 100 mm length, after 100 mm from inlet, film growth have no significantly change except for square microchannel with side 5 mm. The smallest film thickness value is obtained in the square (side 0.5 mm), triangle (side 1 mm) and inverted triangle (side 1 mm) channel, while the biggest value obtained in the square (side 5 mm) channel. But still, by only using film thickness value it is hard to determine the channel performance, so the heat transfer coefficient is needed in order to determine which channel is having the best performance.

Heat transfer coefficient also obtained through manual calculation because based on author trial and error using ANSYS for this case, ANSYS version proved by laboratory couldn't show the film thickness and heat transfer coefficient. From the figure above it is showed that the heat transfer coefficient (h) falls abruptly from inlet (0 mm) to 100 mm and then from 100 mm till the end it falls steadily. Figure 4.2 also showed that the best performance was given from square (side 5 mm) channel. For square channels and rectangular (both orientation) channels, all perform better than circular and triangular channels. Wang and Rose [1] also emphasized in their theoretical approach that the highest heat transfer coefficient obtained in the square channels. Although the boundary condition used in their research was different with the present study, but the best performance result of channel shape is same.

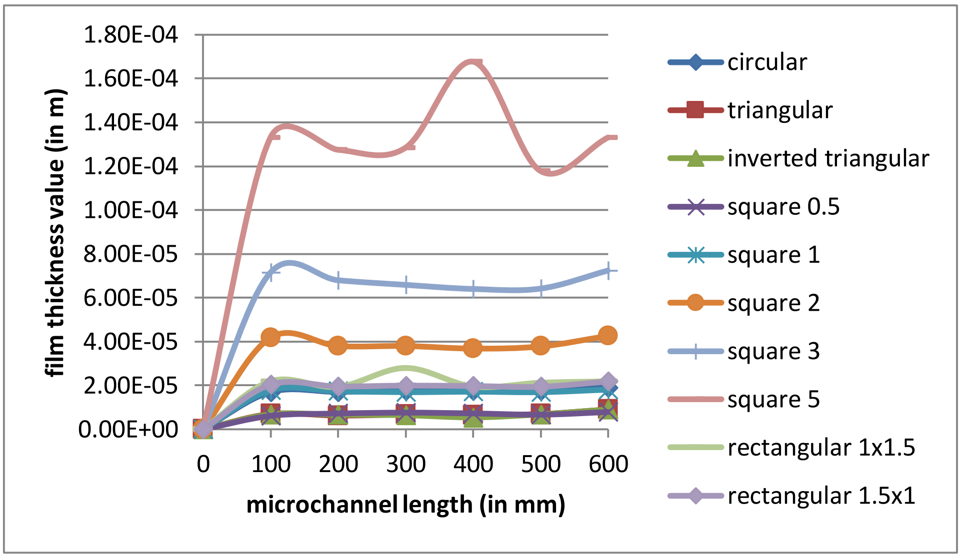



**Figure 4. 1 Film thickness growth along microchannels.**

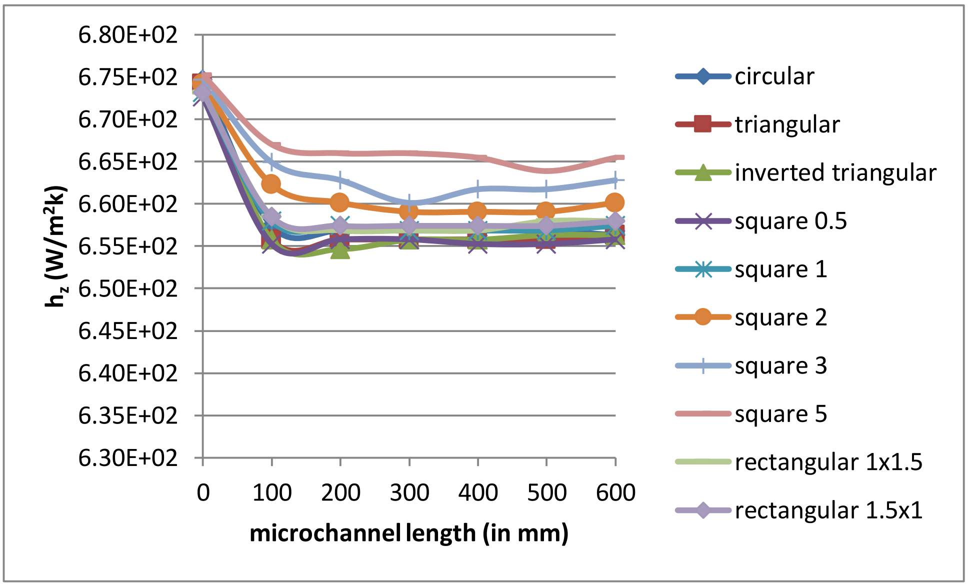



**Figure 4. 2 Heat transfer coefficient along microchannel.**

## 5. Conclusion and recommendation

There are some conclusions and recommendations for the present study. Hopefully these conclusions and recommendations could enrich the understanding about microchannel condensation.

### 5.1 Conclusion

The conclusions of the present study are as follows :

a. Along with the decrease of the temperature, the pressure keeps decreasing along the channel.
b. For this case, the maximum film thickness was obtained in the square channel with side 5 mm. As for the smallest film thickness value is

obtained in the square (side 0.5 mm), triangle (side 1 mm) and inverted triangle (side 1 mm) channel. The film thickness alone can't be used to determine the condensation performance in microchannel, this is emphasized in this present study for square channel with side 5 mm. Although it has the biggest value of film thickness but it has the highest value for heat transfer coefficient.

c. All of the square channel perform better than the other (circular and triangular) channel shapes, with the square channel side 5 mm as the leader.

5.2. Recommendation

The recommendations from the present study are as follows :

a. It would be better to not only investigated one fluid. This is each fluid has its own characteristic, this is proved by some researchers in the literature review that purposely study condensation for specific fluids.
b. The parameters used need to be improved. This because in this study, the condensation only investigated in one wall temperature, thus the result might be different if the study conducted with variation of wall temperature, inlet velocity, inlet temperature and also could include the variation of mass flux in order to get the better understanding towards condensation behavior in microchannels.

**Acknowledgment**

The author aknowledge support from the Computational Fluid Dynamics (CFD) Laboratory and Dr. Akmal Nizam bin Mohammed for this research.

## References


[1] Wang, Hua sheng., Rose, John W., 2006. Film Condensation in Horizontal Microchannels : Effects of Channel Shape. International Journal of Thermal Sciences 45. 1205-1212.

[2] Hao, Tingting. Ma, Xuehu. Lan, Zhong. Jiang, Rui. Fan, Xiaoguang. 2013. Analysis of The Transition Laminar Flow to Intermittent Flow of Stream Condensation in Noncircular Microchannels. International Journal of Heat and Mass Transfer 66. 745-756.

[3] Heo, Jaehyeok. Park, Hanvit. Yun, Rin. 2013. Condensation Heat Transfer and Pressure Drop Characteristic of $CO_2$ in a Microchannel. International Journal of Refrigeration 36. 1657-1668.

[4] Chen, Sihan. Yang, Zhen. Duan, Yuanyuan. Chen, Ying. Wu, Di. 2014. Simulation of Condensation Flow in a Rectangular Microchannel. Chemical Engineering and Processing 76. 60-69.

[5] Mghari, Hicham El. Asbik, Mohammed. Louahlia-Gualous. Voicu Lonut. 2014. Condensation heat Transfer Enhancement in a Horizontal Non-Circular Microchannel. Appllied Thermal Engineering 64. 358-370.

[6] Jiang, Rui. Ma, Xuehu. Lan, Zhong. Bai, Yuxiao. Bai, Tao. 2015. Visualization Study of Condensation of Ethanol-Water Mixtures in Trapezoidal Microchannels. International Journal of Heat and Mass Transfer 90. 339-349.

[7] Fronk, Brian M., Garimella, Srinivas. 2016. Condensation of Carbon Dioxide in Microchannels. International Journal of Heat and Mass Transfer 100. 150-164.

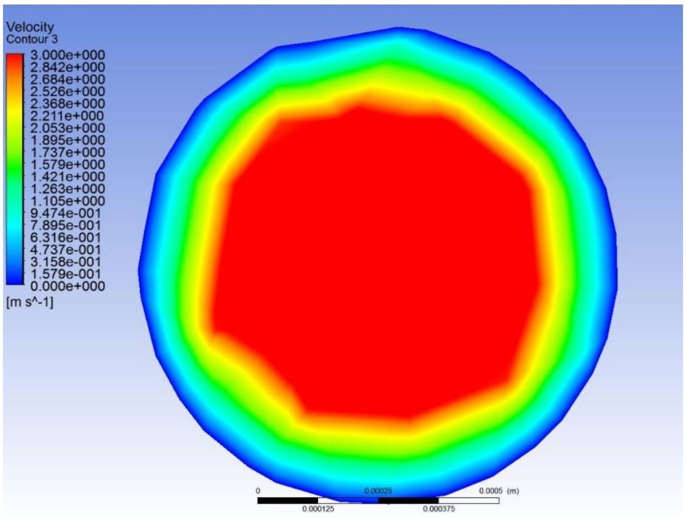
[8] Kaew-On, Jatuporn. Naphattharanun, Nunthaphan. Binmud, Ronee. Wongwises, Somchai. 2016. Condensation Heat Transfer Characteristics of R-134a Flowing Inside Mini Circular and Flattened Tubes. International Journal of Heat and Mass Transfer 102. 86-97.

[9] Kim, Dong Eok. Ahn, Ho Seon. Kwon, Tae-Soon. 2017. Experimental Investigation of Filmwise and Dropwise Condensation Inside Transparent circular Tubes. Applied Thermal Engineering 110. 412-423.

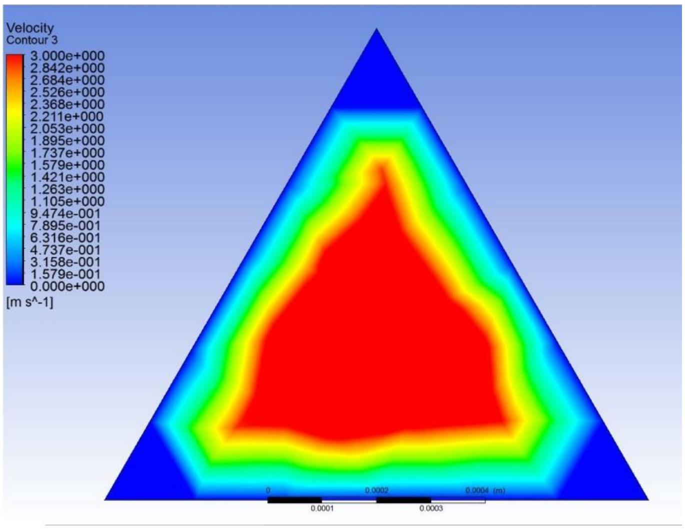
[10] Agarwall, A. Garimella, Srinivas. 2010. Representative Results for Condensation Measurement at Hydraulic Diameters 100 microns. Journal of Heat Transfer 132. 1-12.

[11] Incropera et al. 2006. Fundamentals of Heat and Mass Transfer sixth edition. Wiley.

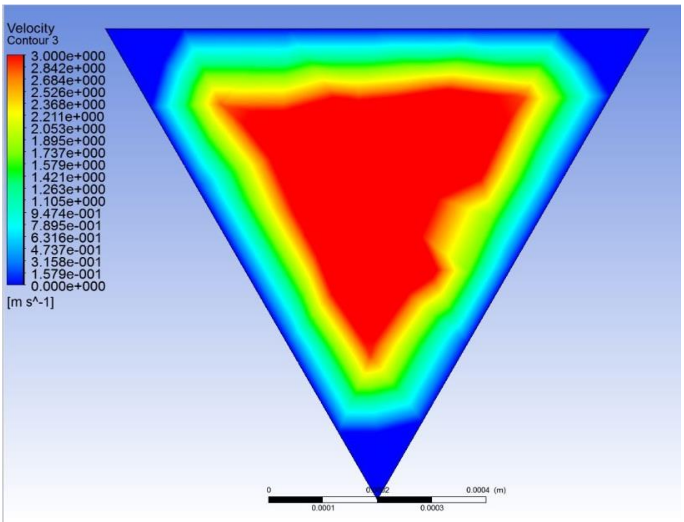
## APPENDIX



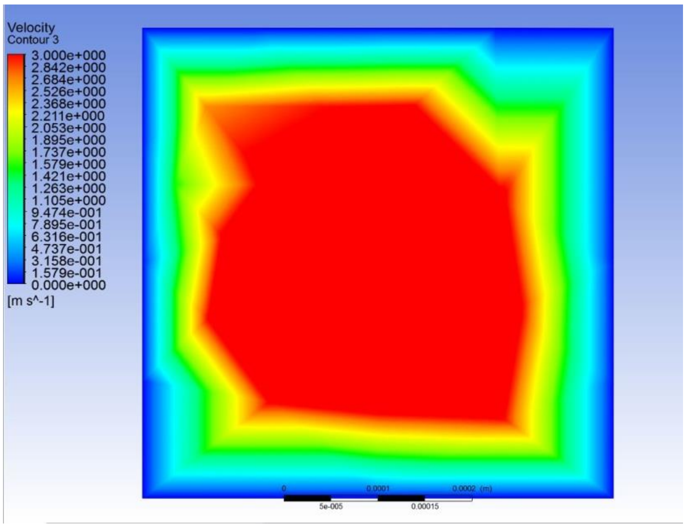

**A. 1 Contour of velocity 300 mm from inlet, circular channel.**



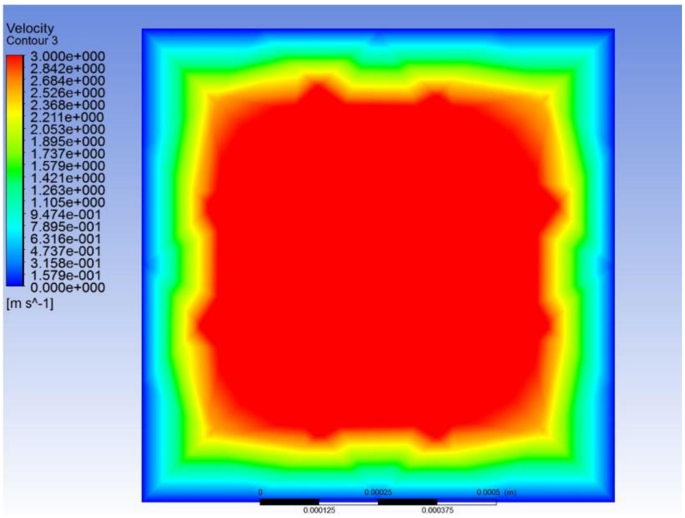

**A. 2 Contour of velocity 300 mm from inlet, triangular channel.**



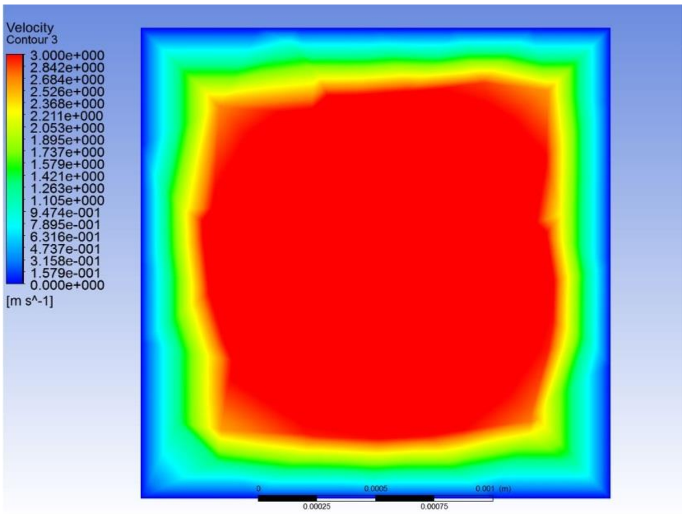

**A. 3 Contour of velocity 300 mm from inlet, inverted triangular channel.**



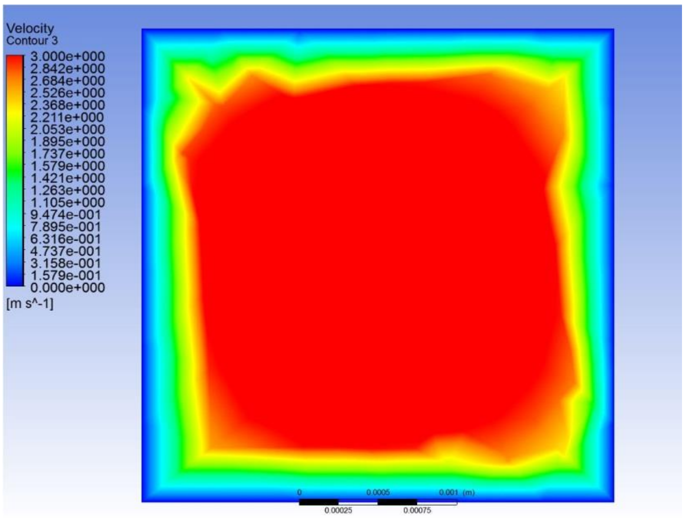

**A. 4 Contour of velocity 300 mm from inlet, square channel side 0,5 mm.**



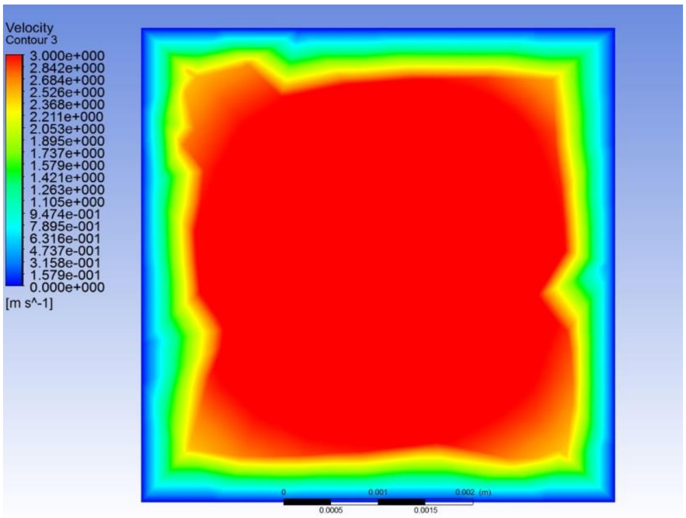

**A. 5 Contour of velocity 300 mm from inlet, square channel side 1 mm.**



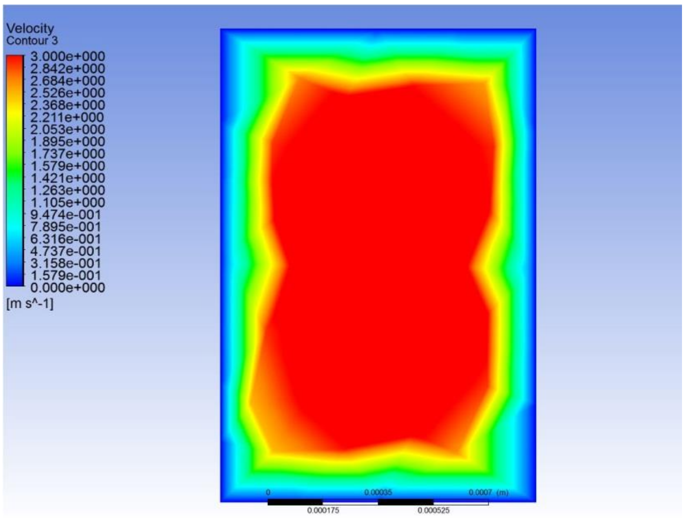

**A. 6 Contour of velocity 300 mm from inlet, square channel side 2 mm.**



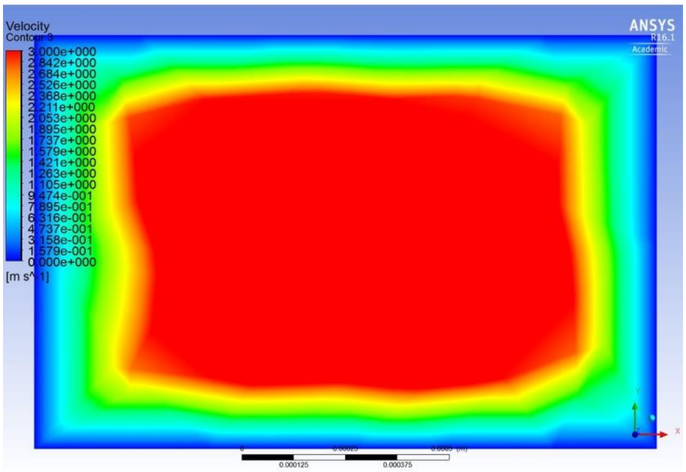

**A. 7 Contour of velocity 300 mm from inlet, square channel side 3 mm.**



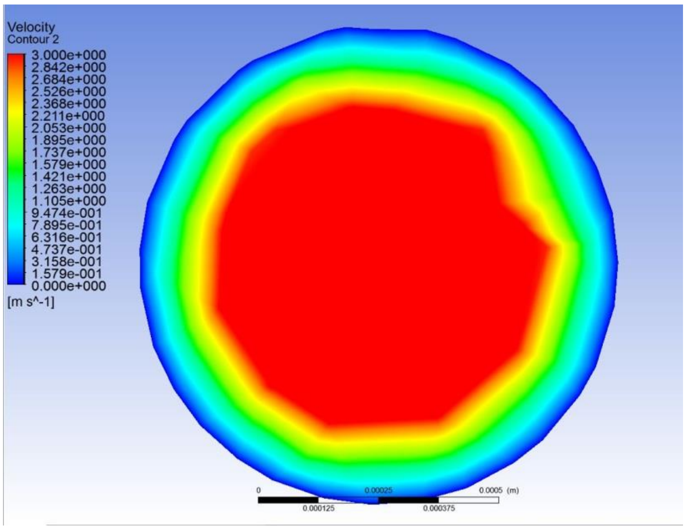

**A. 8 Contour of velocity 300 mm from inlet, square channel side 5 mm.**



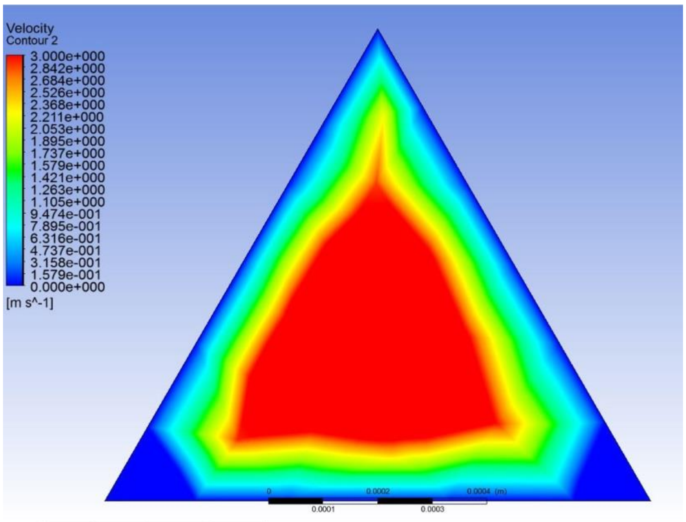

**A. 9 Contour of velocity 300 mm from inlet, rectangular channel side 1x1,5 mm.**



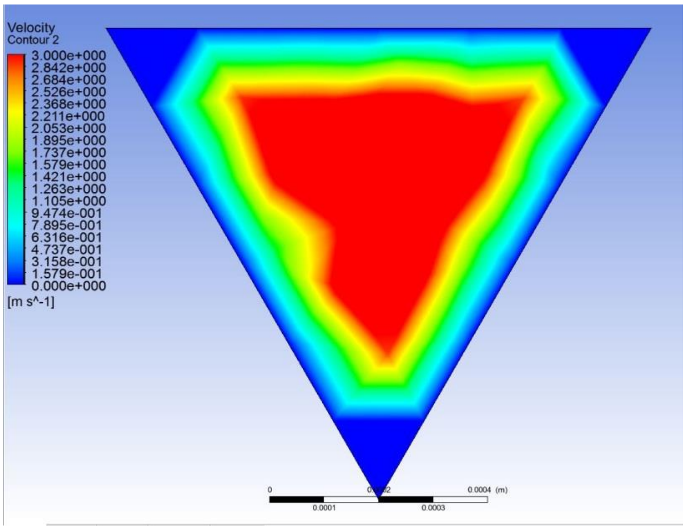

**A. 10 Contour of velocity 300 mm from inlet, rectangular channel side 1,5x1 mm.**



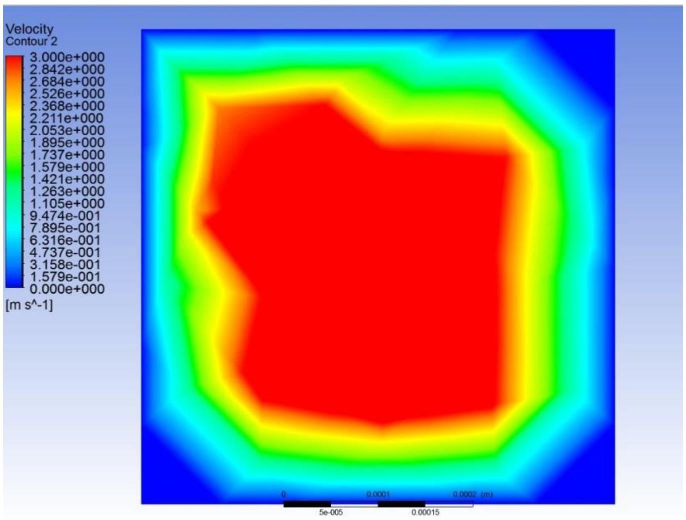

**A. 11 Contour of velocity 400 mm from inlet, circular channel.**



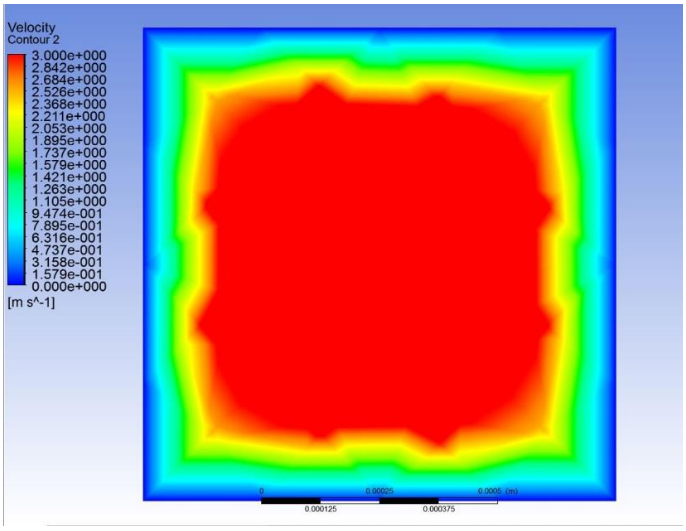

**A. 12 Contour of velocity 400 mm from inlet, triangular channel.**



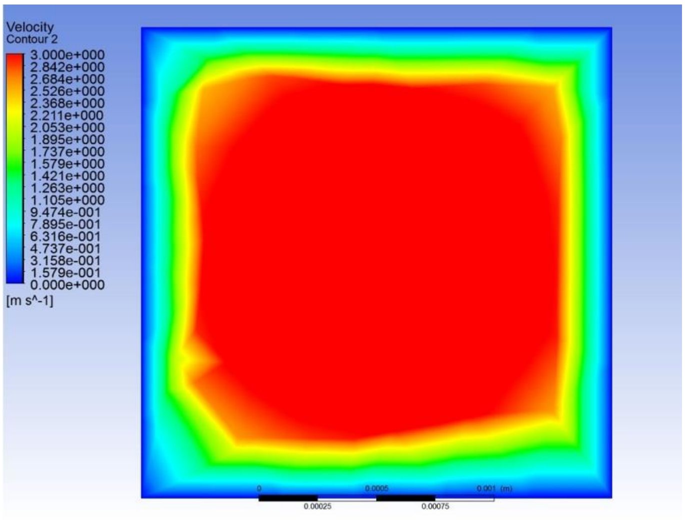

**A. 13 Contour of velocity 400 mm from inlet, inverted triangular channel.**



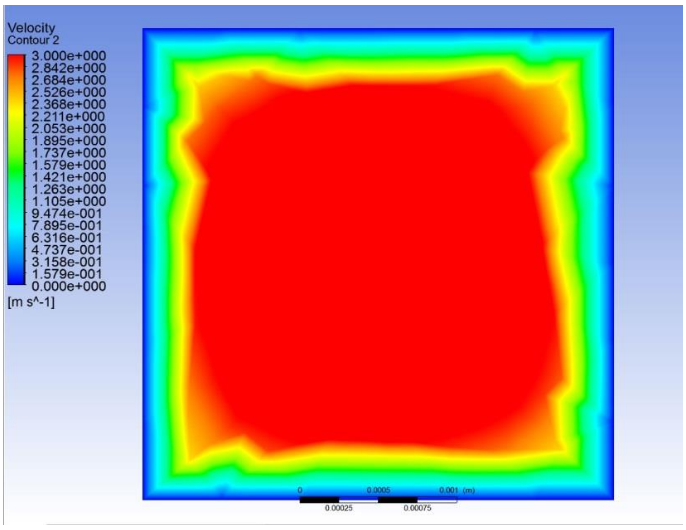

**A. 14 Contour of velocity 400 mm from inlet, square channel side 0,5 mm.**



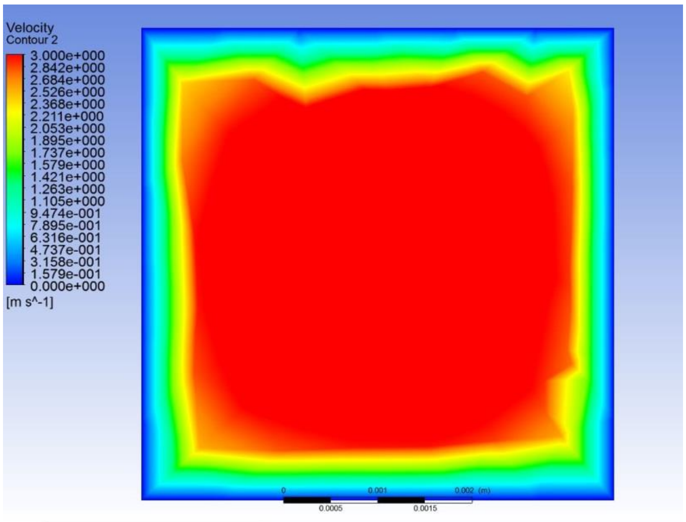

**A. 15 Contour of velocity 400 mm from inlet, square channel side 1 mm.**



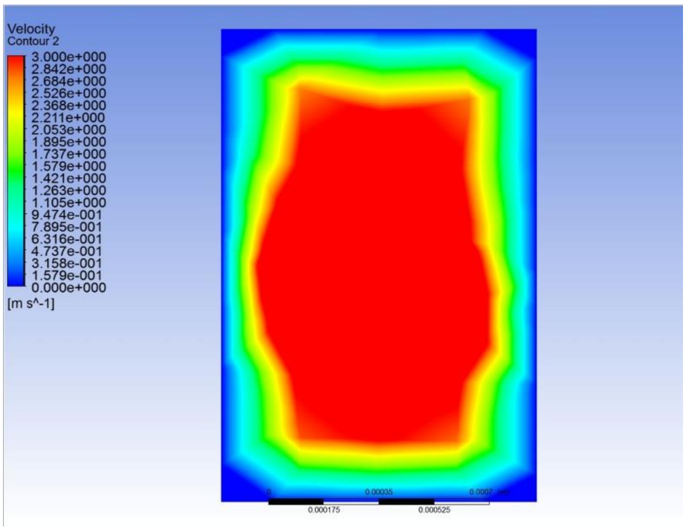

**A. 16 Contour of velocity 400 mm from inlet, square channel side 2 mm.**



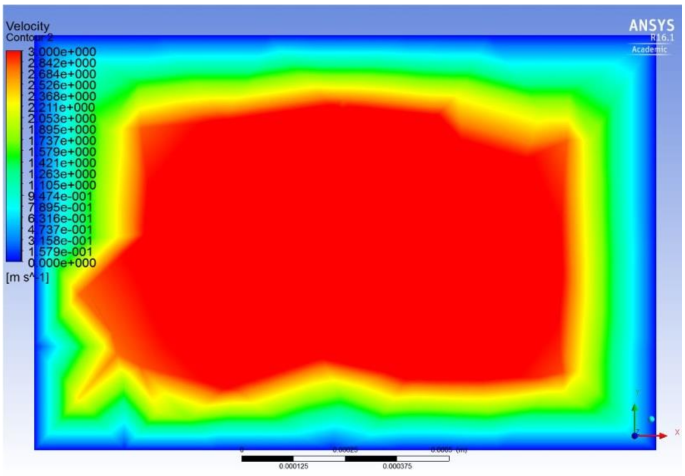

A. 17 Contour of velocity 400 mm from inlet, square channel side 3 mm.




A. 18 Contour of velocity 400 mm from inlet, square channel side 5 mm.




**A. 19 Contour of velocity 400 mm from inlet, rectangular channel side 1x1,5 mm.**




**A. 20 Contour of velocity 400 mm from inlet, rectangular channel side 1,5x1 mm.**